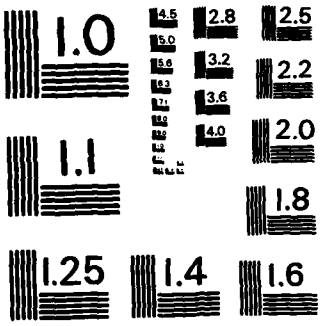
AD-A121 719 MAGNETIC AND ELECTRICAL PROPERTIES OF [illegible]
OXIDE(III)(U) BROWN UNIV PROVIDENCE RI DEPT OF
CHEMISTRY H LEIVA ET AL. 16 NOV 82 TR-22

UNCLASSIFIED N00014-77-C-0387 F/G 20/3 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963 - A

(12)

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: 22 — GOVT ACCESSION NO.: AD-A121719	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): MAGNETIC AND ELECTRICAL PROPERTIES OF RHODIUM(III) OXIDE(III)	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER: 22
7. AUTHOR(s): H. Leiva, R. Kershaw, K. Dwight, and A. Wold	8. CONTRACT OR GRANT NUMBER(s): N00014-77-C-0387
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Professor Aaron Wold, Brown University, Department of Chemistry, Providence, R.I. 02912	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: NR-359-653
11. CONTROLLING OFFICE NAME AND ADDRESS: Dr. David Nelson Code 472, Office of Naval Research, Arlington, Virginia 22217	12. REPORT DATE: November 16, 1982
	13. NUMBER OF PAGES: 17
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report)
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

SUBMITTED TO THE MATERIALS RESEARCH BULLETIN

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Orthorhombic Corundum Related Structure

Pauli Paramagnetism

P-Type Conduction

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Rh_2O_3(III) crystallizes with an orthorhombic corundum-related structure and is Pauli paramagnetic. Its electrical behavior is characterized by a small activation energy, and the Seebeck coefficient indicates p-type conduction. This oxide may be considered as a semimetal, and its properties are discussed in terms of face and edge sharing of RhO_6 octahedra.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

OFFICE OF NAVAL RESEARCH

Contract N00014-77-C-0387

Task No. NR-359-653

TECHNICAL REPORT NO. 22

Magnetic and Electrical Properties of Rhodium(III)OXIDE(III)

by

H. Leiva, R. Kershaw, K. Dwight, and A. Wold

Department of Chemistry

Brown University

Providence, Rhode Island 02912

Prepared for Publication

in the

Materials Research Bulletin

November 16, 1982

A

MAGNETIC AND ELECTRICAL PROPERTIES OF RHODIUM(III)OXIDE(III)

H. Leiva, R. Kershaw, K. Dwight, and A. Wold
Department of Chemistry, Brown University
Providence, Rhode Island 02912

ABSTRACT:

Rh_2O_3(III) crystallizes with an orthorhombic corundum-related structure and is Pauli paramagnetic. Its electrical behavior is characterized by a small activation energy, and the Seebeck coefficient indicates p-type conduction. This oxide may be considered as a semimetal, and its properties are discussed in terms of face and edge sharing of RhO_6 octahedra.

Introduction

The synthesis and crystallographic properties of the compounds belonging to the Rh-O system have been the subject of numerous studies (1-8). It has been found that three rhodium(III) oxides can exist under different conditions: the low temperature, low pressure form (Rh_2O_3(I)); a high temperature, high pressure structure (Rh_2O_3(II)); and a high temperature, ambient pressure compound (Rh_2O_3(III)).

Rh_2O_3(I) has been obtained when rhodium compounds such as the hydrous oxide, nitrate, sulfate, or chloride are decomposed between 600-750°C (1-3). The resulting product crystallizes with the corundum structure, and when this phase is heated between 750-1000°C, it transforms irreversibly to Rh_2O_3(III), which is more thermally stable. The phase Rh_2O_3(III) has also been prepared by direct oxidation of rhodium metal (2,5). A major difficulty in obtaining pure samples of Rh_2O_3(III) is its tendency to dissociate at relatively low temperature. The decomposition temperature depends on the oxygen pressure, and decreases from 1130°C at 760 torr, to 900°C at 10 torr (3). In a reducing atmosphere, this oxide decomposes readily to rhodium metal at about 100-150 C°(3). Rhodium(III)oxide(III) crystallizes with an

orthorhombic corundum-related structure (space group Pbca) (5). Rh_2O_3(II) has been obtained by heating rhodium oxide (produced by heating rhodium(III) chloride in air at 800°C) at 1200-1500°C and 65 kb pressure (6).

Although Rh_2O_3(I) and Rh_2O_3(III) are the most common forms of the rhodium(III) oxides, their magnetic and electronic properties have not been completely determined. Rhodium(III)oxide(II) has been reported to be a semiconductor with a room temperature resistivity of 130 Ω-cm and an activation energy of 0.16 (6), but the nature of this behavior has not been explained.

In this study, Rh_2O_3(III) was prepared and characterized with regard to its crystallographic, magnetic, and electrical properties.

Synthesis

Rhodium(III)oxide(III) was prepared by the oxidation of finely divided rhodium metal (Engelhard Inc. 99.99%) in an oxygen atmosphere at 800°C until constant weight was obtained. A silica tube was used to contain the rhodium powder. The product was ground each day in an agate mortar, and then reheated. After the last heating, the compound was allowed to cool slowly to room temperature. The metal-to-oxygen ratio was determined by reduction of the final product at 900°C with a mixture of 85% argon - 15% hydrogen. The oxygen content obtained was 18.9 weight percent, which corresponds to the composition Rh_2O_3.

Discs of Rh_2O_3(III) were made by pressing aliquots of the polycrystalline material at 50 kb for 30 minutes at 650°C. Under these conditions, only Rh_2O_3(III) exists, since Rh_2O_3(II) requires higher temperatures and pressure to form. After pressing, the discs were cooled slowly, transferred to a silica tube, and annealed in air for six days at 600°C to ensure reoxidation of any rhodium metal which might have been formed during the sintering process. The discs were then examined by x-ray analysis in order to confirm the existence of pure, homogeneous Rh_2O_3(III). No changes of the diffraction patterns were observed when compared to the starting polycrystalline Rh_2O_3(III).

The density of these discs was determined using a hydrostatic technique based on Archimedes' principle (9). Perfluoro-1-methyldecalin (Pierce Chemical Co.) was used as the liquid medium, and its density was calibrated before each measurement with a high-purity silicon crystal ($D_{22°C}$ = 2.328 g/cm^3). An average density of 7.80 (g/cm^3) was found for the discs, which is greater than 95% of the calculated density of Rh_2O_3(III) (8.19 g/cm^3).

Magnetic and Electrical Properties

Magnetic measurements were performed using a Faraday balance (10). The magnetic susceptibility was measured as a function of temperature from liquid nitrogen to 300K at a field strength of 10.4 kOe. The data were then corrected for core diamagnetism (-32×10^{-4} emu/g Rh_2O_3) (11). The lack of any field dependency of the susceptibility showed the absence of ferromagnetic impurities.

The van der Pauw method (12) was used to measure the electrical resistivities. Contacts were made by the ultrasonic soldering of indium directly onto the sintered discs of Rh_2O_3(III), and their ohmic behaviors were established by measuring their current-voltage characteristics. The Seebeck coefficient was obtained by applying a temperature gradient to a sintered disc of Rh_2O_3(III) and recording the resulting voltage difference.

Results and Discussion

The crystal structure of Rh_2O_3(III) was first determined by Biesterbos and Hornstra (5). The structure projected along the orthorhombic x-axis is shown in Figure 1. All of the rhodium ions are octahedrally coordinated by oxygen ions, which in turn are bonded to four rhodium ions. It can be seen that pairs of $[RhO_6]$ octahedra share faces, and each pair is connected to another pair within the plane, and to pairs above and below the plane, by means of edge-sharing.

Rh_2O_3(III) prepared in this study was orthorhombic (space group Pbca), and the following cell constants were determined: a = 5.146(3)Å, b = 5.440(1)Å, and c = 14.71(1)Å. These results are in good agreement with those reported previously for Rh_2O_3(III) (2,5).

FIG. 1

Unit cell in the structure of Rh_2O_3(III) as viewed along the orthorhombic x-axis.

Magnetic Properties

The magnetic data for Rh_2O_3(III) shown in Figure 2 indicate a weak temperature-independent paramagnetism (Pauli paramagnetic behavior) with $\chi = 150 \times 10^{-6}$ emu/mole Rh_2O_3 (0.59×10^{-6} emu/g Rh_2O_3). This behavior implies probable delocalization of electrons in Rh_2O_3.

Electrical Properties

The temperature variation of the electrical resistivity of Rh_2O_3(III) is shown in Figure 3; the resistivity increases slightly from 4Ω-cm at room temperature to 41Ω-cm at liquid nitrogen temperature. Figure 3 shows a curvature and yields a maximum value for the activation energy of less than 0.05. This indicates that Rh_2O_3(III) does not follow typical semiconductor behavior. A value of +37μV/°C was obtained for the Seebeck coefficient of Rh_2O_3(III). The magnitude of this result also suggests metallic behavior; the sign indicates predominantly p-type conduction.

FIG. 2

Variation of magnetic susceptibility with temperature for Rh_2O_3(III).

FIG. 3

Variation of resistivity with temperature for Rh_2O_3(III).

The magnetic and electrical behavior of Rh_2O_3(III) may be explained by assuming the existence of narrow d-bands and acceptor levels located slightly above them. Such bands probably form because each RhO_6 octahedra shares a face and edges with neighboring octahedra. Consequently, the t_{2g} orbitals of each rhodium ion are always directed to the nearest neighboring rhodium ions along these directions. In Rh_2O_3(III), the Rh-Rh distance across the shared face is 2.69±0.05Å (5), which is similar to the equivalent distance reported for V_2O_3. V_2O_3 crystallizes with the related corundum structure and possesses V-V bands formed by t_{2g}-t_{2g} interactions (13,14). Since metal-metal distances in these structures allow for the overlapping of 3d orbitals, it is expected that the same overlap may occur in Rh_2O_3(III), considering the larger extension of 4d wave functions. By symmetry considerations, any overlap of orbitals across shared edges may also have some oxygen character.

In Rh_2O_3(III) the existence of acceptor levels located above filled valence bands is consistent with the existence of Rh(IV) ions. The existence of such acceptor levels close to the valence band is consistent with the small observed activation energy obtained from Figure 3. Electrons from the filled valence band can easily be promoted to the acceptor levels, leaving behind holes which can give rise to the observed p-type conduction.

Conclusions

Rh_2O_3(III) has been prepared and crystallizes with an orthorhombic corundum-related structure. The building block of this framework is an RhO_6 octahedron, which can share a face and edges with neighboring octahedra. This type of bonding allows for the possibility of direct rhodium-rhodium or indirect rhodium-oxygen-rhodium interactions, and appears to determine the electrical and magnetic properties of the oxide. Rh_2O_3(III) shows Pauli paramagnetism, and its electrical behavior is characterized by a small activation energy. The Seebeck coefficient indicates p-type conduction. This behavior is consistent with the formation of a filled d-band, with rhodium or rhodium-oxygen character, and acceptor levels lying close to this band. These levels are due to the presence of a small amount of Rh(IV) in the Rh_2O_3(III).

The determination of the magnetic properties as well as some of the electrical properties of Rh_2O_3(III) indicates that this oxide may be considered a semimetal.

Acknowledgements

The authors would like to thank the Office of Naval Research, Arlington, Virginia, for the support of Hector Leiva and Kirby Dwight. Acknowledgement is also made to the Materials Research Laboratory Program at Brown University.

References

1. G. Lunde; Z. Anorg. Chem. 163, 345 (1927).

2. A. Wold, R.J. Arnott, W.J. Croft; Inorg. Chem. 2, No. 5, 972 (1963).

3. G. Bayer and H.G. Wiedemann; Thermochimica Acta 15, 213 (1976).

4. J.M.D. Coey; Acta Cryst. B26, 1876 (1970).

5. J.W.M. Biesterbos and J. Hornstra; J. Less Common Metals 30, 121 (1973).

6. R.D. Shannon and C.T. Prewitt; J. Solid State Chemistry 2, 134 (1970).

7. K.R. Poeppelmeier and G.B. Ansell; J. Crystal Growth 51, 587 (1981).

8. O. Muller and R. Roy; J. Less Common Metals 16, 129 (1968).

9. R.L. Adams; Ph.D. Thesis, Brown University (1973).

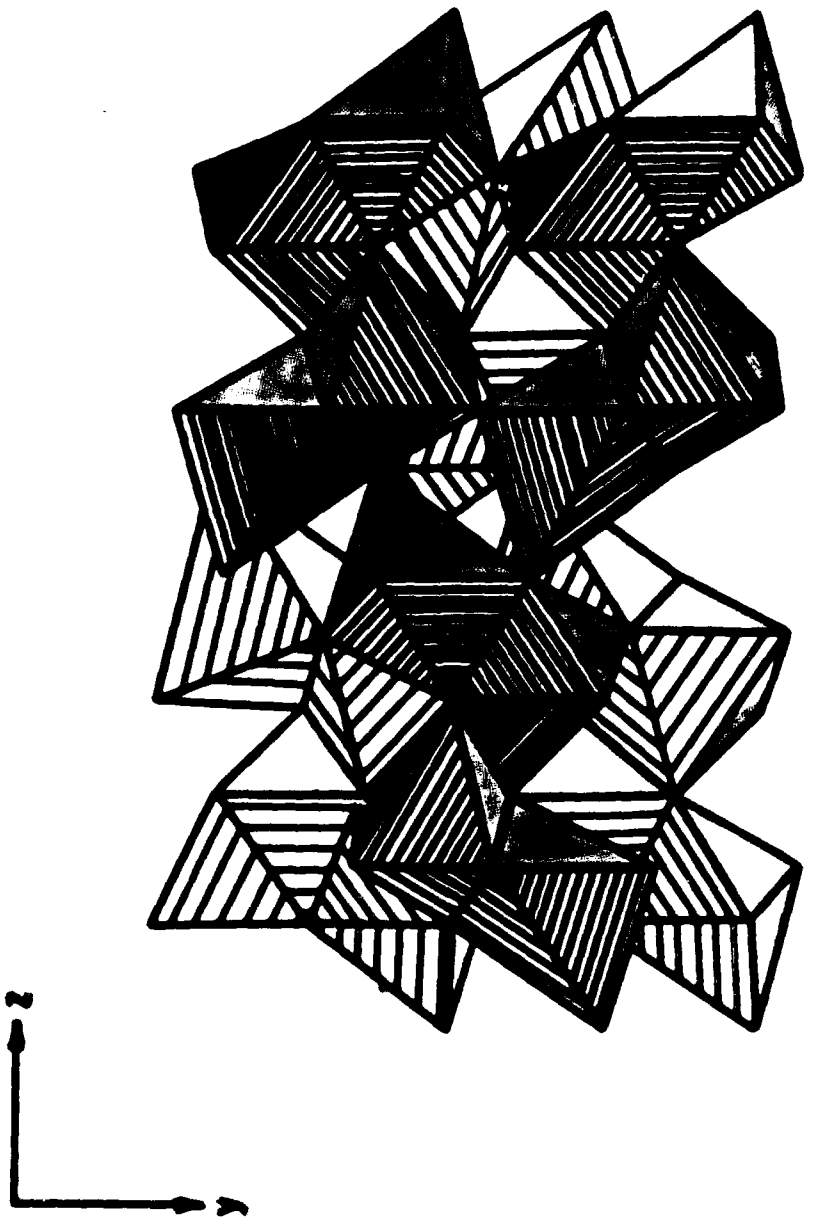
10. B. Morris and A. Wold; Rev. Sci. Inst. 39, 1937 (1968).

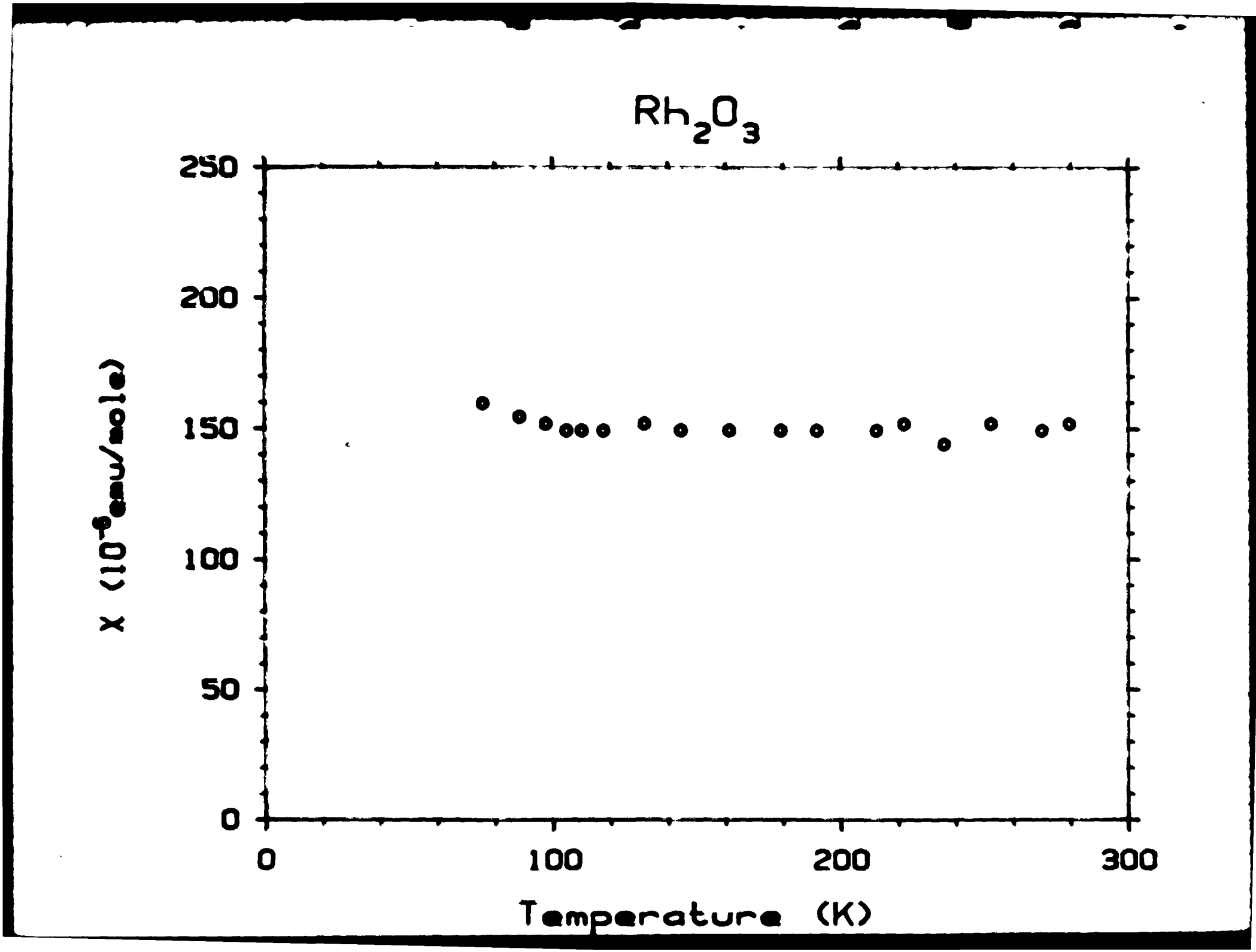
11. P.W. Selwood; "Magnetochemistry"; Interscience Pub. Co., 1956, New York, 2nd Ed.

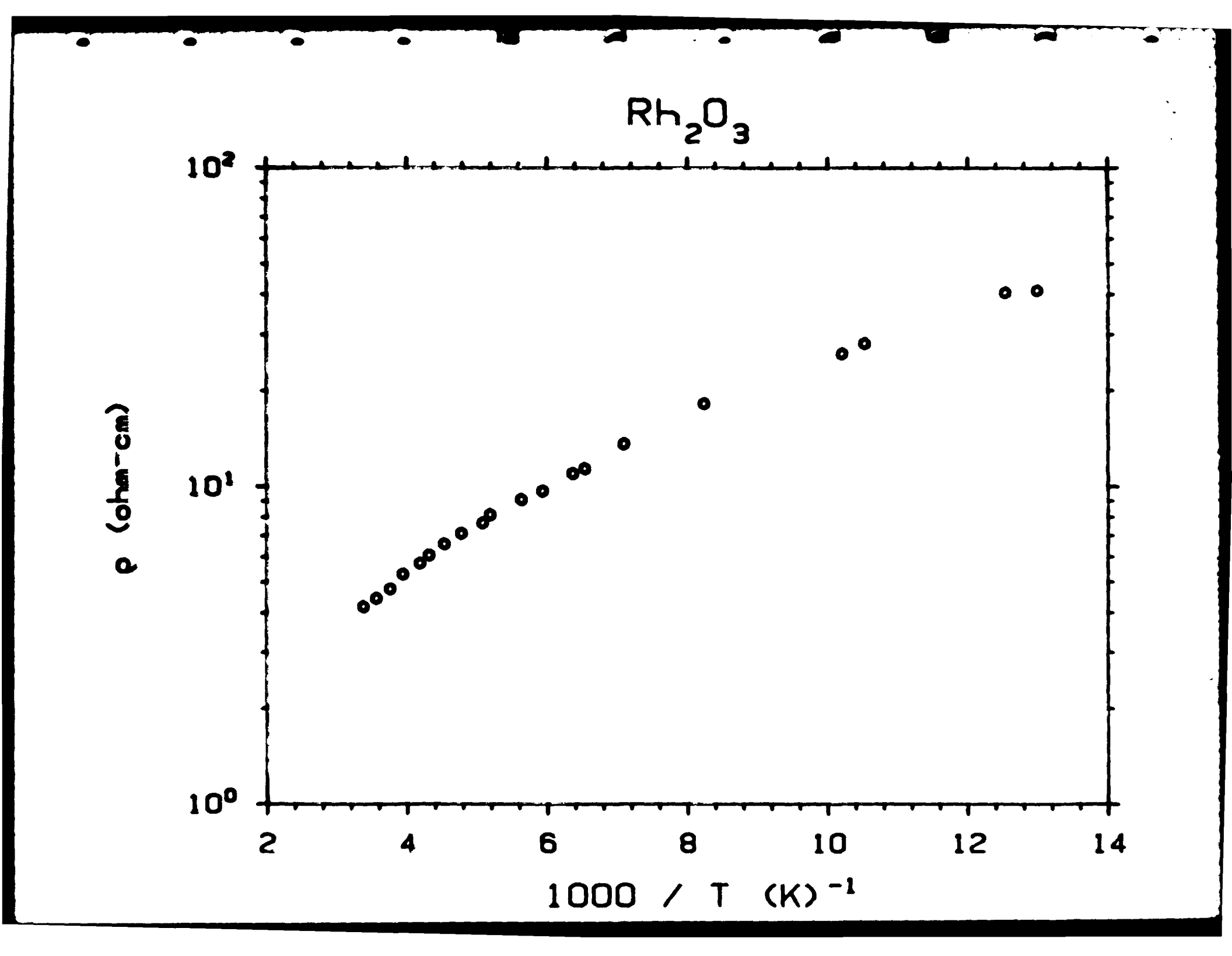
12. L.J. van der Pauw; Philips Res. Rep. 13, 1 (1958).

13. J.B. Goodenough; "Magnetism and Chemical Bond"; Interscience Div. of John Wiley and Sons, 1963, New York-London.

14. C.T. Prewitt, R.D. Shannon, D.B. Rogers and A.W. Sleight; Inorg. Chem. 8, No. 9, 1985 (1969).




Rh_2O_3
250
200
150
100
50
0
χ (10^{-6}emu/mole)
0
100
200
300
Temperature (K)


Rh_2O_3
10^2
10^1
10^0
ρ (ohm-cm)
2
4
6
8
10
12
14
1000 / T (K)$^{-1}$

472:GAN:716-4
94/GEN

TECHNICAL REPORT DISTRIBUTION LIST, GEN

	No. Copies
Office of Naval Research Attn: Code 413 800 North Quincy Street Arlington, Virginia 22217	2
ONR Pasadena Detachment Attn: Dr. R. J. Marcus 1030 East Green Street Pasadena, California 91106	1
Commander, Naval Air Systems Command Attn: Code 310C (H. Rosenwasser) Department of the Navy Washington, D.C. 20360	1
Defense Technical Information Center Building 5, Cameron Station Alexandria, Virginia 22314	12
Dr. Fred Saalfeld Chemistry Division, Code 6100 Naval Research Laboratory Washington, D.C. 20375	1
U.S. Army Research Office Attn: CRD-AA-IP P. O. Box 12211 Research Triangle Park, N.C. 27709	1
Mr. Vincent Schaper DTNSRDC Code 2803 Annapolis, Maryland 21402	1
Naval Ocean Systems Center Attn: Dr. S. Yamamoto Marine Sciences Division San Diego, California 91232	1
Naval Ocean Systems Center Attn: Mr. Joe McCartney San Diego, California 92152	1
Naval Weapons Center Attn: Dr. A. B. Amster, Chemistry Division China Lake, California 93555	1
Naval Civil Engineering Laboratory Attn: Dr. R. W. Drisko Port Hueneme, California 93401	1
Dean William Tolles Naval Postgraduate School Monterey, California 93940	1
Scientific Advisor Commandant of the Marine Corps (Code RD-1) Washington, D.C. 20380	1
Naval Ship Research and Development Center Attn: Dr. G. Bosmajian, Applied Chemistry Division Annapolis, Maryland 21401	1
Mr. John Boyle Materials Branch Naval Ship Engineering Center Philadelphia, Pennsylvania 19112	1
Mr. A. M. Anzalone Administrative Librarian PLASTEC/ARRADCOM Bldg 3401 Dover, New Jersey 07801	1

472:GAN:716-4
94/359

TECHNICAL REPORT DISTRIBUTION LIST, 359

	No. Copies
Dr. Paul Delahay Department of Chemistry New York University New York, New York 10003	1
Dr. E. Yeager Department of Chemistry Case Western Reserve University Cleveland, Ohio 41106	1
Dr. D. N. Bennion Department of Chemical Engineering Brigham Young University Provo, Utah 84602	1
Dr. R. A. Marcus Department of Chemistry California Institute of Technology Pasadena, California 91125	1
Dr. J. J. Auborn Bell Laboratories Murray Hill, New Jersey 07974	1
Dr. Adam Heller Bell Laboratories Murray Hill, New Jersey 07974	1
Dr. T. Katan Lockheed Missiles and Space Co., Inc. P. O. Box 504 Sunnyvale, California 94088	1
Dr. Joseph Singer, Code 302-1 NASA-Lewis 21000 Brookpark Road Cleveland, Ohio 44135	1
Dr. B. Brummer EIC Incorporated 55 Chapel Street Newton, Massachusetts 02158	1
Library P. R. Mallory and Company, Inc. Northwest Industrial Park Burlington, Massachusetts 01803	1
Dr. P. J. Hendra Department of Chemistry University of Southampton Southampton SO0 5NH United Kingdom	1
Dr. Sam Perone Chemistry & Materials Science Department Laurence Livermore National Lab. Livermore, California 94550	1
Dr. Royce W. Murray Department of Chemistry University of North Carolina Chapel Hill, North Carolina 27514	1
Naval Ocean Systems Center Attn: Technical Library San Diego, California 92152	1
Dr. C. E. Mueller The Electrochemistry Branch Materials Division, Research and Technology Department Naval Surface Weapons Center White Oak Laboratory Silver Spring, Maryland 20910	1
Dr. G. Goodman Johnson Controls 5757 North Green Bay Avenue Milwaukee, Wisconsin 53201	1
Dr. J. Boechler Electrochimica Corporation Attn: Technical Library 2485 Charleston Road Mountain View, California 94040	1
Dr. P. P. Schmidt Department of Chemistry Oakland University Rochester, Michigan 48063	1

TECHNICAL REPORT DISTRIBUTION LIST, 359

	No. Copies
Dr. H. Richtol Chemistry Department Rensselaer Polytechnic Institute Troy, New York 12181	1
Dr. A. B. Ellis Chemistry Department University of Wisconsin Madison, Wisconsin 53706	1
Dr. M. Wrighton Chemistry Department Massachusetts Institute of Technology Cambridge, Massachusetts 02139	
Larry E. Plew Naval Weapons Support Center Code 30736, Building 2906 Crane, Indiana 47522	1
S. Ruby DOE (STOR) 600 E Street Providence, Rhode Island 02192	1
Dr. Aaron Wold Brown University Department of Chemistry Providence, Rhode Island 02192	1
Dr. R. C. Chudacek McGraw-Edison Company Edison Battery Division Post Office Box 28 Bloomfield, New Jersey 07003	1
Dr. A. J. Bard University of Texas Department of Chemistry Austin, Texas 78712	1
Dr. M. M. Nicholson Electronics Research Center Rockwell International 3370 Miraloma Avenue Anaheim, California	1
Dr. R. P. Van Duyne Department of Chemistry Northwestern University Evanston, Illinois 60201	1
Dr. B. Stanley Pons Department of Chemistry University of Alberta Edmonton, Alberta CANADA T6G 2G2	1
Dr. Michael J. Weaver Department of Chemistry Michigan State University East Lansing, Michigan 48824	1
Dr. R. David Rauh EIC Corporation 55 Chapel Street Newton, Massachusetts 02158	1
Dr. J. David Margerum Research Laboratories Division Hughes Aircraft Company 3011 Malibu Canyon Road Malibu, California 90265	1
Dr. Martin Fleischmann Department of Chemistry University of Southampton Southampton 509 5NH England	1
Dr. Janet Osteryoung Department of Chemistry State University of New York at Buffalo Buffalo, New York 14214	1
Dr. R. A. Osteryoung Department of Chemistry State University of New York at Buffalo Buffalo, New York 14214	1

TECHNICAL REPORT DISTRIBUTION LIST, 359

	No. Copies
Dr. Donald W. Ernst Naval Surface Weapons Center Code R-33 White Oak Laboratory Silver Spring, Maryland 20910	1
Dr. R. Nowak Naval Research Laboratory Code 6130 Washington, D.C. 20375	1
Dr. John F. Houlihan Shenango Valley Campus Pennsylvania State University Sharon, Pennsylvania 16146	1
Dr. D. F. Shriver Department of Chemistry Northwestern University Evanston, Illinois 60201	1
Dr. D. H. Whitmore Department of Materials Science Northwestern University Evanston, Illinois 60201	1
Dr. Alan Bewick Department of Chemistry The University Southampton, S09 5NH England	
Dr. A. Himy NAVSEA-5433 NC #4 2541 Jefferson Davis Highway Arlington, Virginia 20362	
Dr. John Kincaid Department of the Navy Strategic Systems Project Office Room 901 Washington, D.C. 20376	
Mr. James R. Moden Naval Underwater Systems Center Code 3632 Newport, Rhode Island 02840	1
Dr. Bernard Spielvogel U. S. Army Research Office P. O. Box 12211 Research Triangle Park, NC 27709	1
Dr. Denton Elliott Air Force Office of Scientific Research Bolling AFB Washington, D.C. 20332	1
Dr. David Aikens Chemistry Department Rensselaer Polytechnic Institute Troy, New York 12181	1
Dr. A. P. B. Lever Chemistry Department York University Downsview, Ontario M3J1P3 Canada	1
Dr. Stanislaw Szpak Naval Ocean Systems Center Code 6343 San Diego, California 95152	1
Dr. Gregory Farrington Department of Materials Science and Engineering University of Pennsylvania Philadelphia, Pennsylvania 19104	
Dr. Bruce Dunn Department of Engineering & Applied Science University of California Los Angeles, California 90024	

TECHNICAL REPORT DISTRIBUTION LIST, 359

	No. Copies
M. L. Robertson Manager, Electrochemical and Power Sonices Division Naval Weapons Support Center Crane, Indiana 47522	1
Dr. Elton Cairns Energy & Environment Division Lawrence Berkeley Laboratory University of California Berkeley, California 94720	1
Dr. Micha Tomkiewicz Department of Physics Brooklyn College Brooklyn, New York 11210	1
Dr. Lesser Blum Department of Physics University of Puerto Rico Rio Piedras, Puerto Rico 00931	1
Dr. Joseph Gordon, II IBM Corporation K33/281 5600 Cottle Road San Jose, California 95193	1
Dr. Robert Somoano Jet Propulsion Laboratory California Institute of Technology Pasadena, California 91103	1
Dr. Johann A. Joebstl USA Mobility Equipment R&D Command DRDME-EC Fort Belvior, Virginia 22060	1
Dr. Judith H. Ambrus NASA Headquarters M.S. RTS-6 Washington, D.C. 20546	1
Dr. Albert R. Landgrebe U.S. Department of Energy M.S. 6B025 Forrestal Building Washington, D.C. 20595	1
Dr. T. Marks Department of Chemistry Northwestern University Evanston, Illinois 60201	1
Dr. D. Cipris Allied Corporation P. O. Box 3000R Morristown, New Jersey 07960	1
Dr. M. Philpot IBM Corporation 5600 Cottle Road San Jose, California 95193	1
Dr. Donald Sandstrom Washington State University Department of Physics Pullman, Washington 99164	1
Dr. Carl Kannewurf Northwestern University Department of Electrical Engineering and Computer Science Evanston, Illinois 60201	1
Dr. Edward Fletcher University of Minnesota Department of Mechanical Engineering Minneapolis, Minnesota 55455	1
Dr. John Fontanella U.S. Naval Academy Department of Physics Annapolis, Maryland 21402	1
Dr. Martha Greenblatt Rutgers University Department of Chemistry New Brunswick, New Jersey 08903	1
Dr. John Wassib Kings Mountain Specialties P. O. Box 1173 Kings Mountain, North Carolina 28086	1

TECHNICAL REPORT DISTRIBUTION LIST, 359

	No. Copies	No. Copies
Dr. J. J. Brophy University of Utah Department of Physics Salt Lake City, Utah 84112	1	
Dr. Walter Roth Department of Physics State University of New York Albany, New York 12222	1	
Dr. Thomas Davis National Bureau of Standards Polymer Science and Standards Division Washington, D.C. 20234	1	
Dr. Charles Martin Department of Chemistry Texas A&M University	1	
Dr. Anthony Sammells Institute of Gas Technology 3424 South State Street Chicago, Illinois 60616	1	
Dr. H. Tachikawa Department of Chemistry Jackson State University Jackson, Mississippi 39217	1	
Dr. W. M. Risen Department of Chemistry Brown University Providence, Rhode Island	1	